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THE TEMPERATURE RELATIONS BETWEEN WATER AND AIR AT ST. ANDREWS, N.B.

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Abstract

Monthly normals for the water and air at St. Andrews, N. B. have been determined. These monthly normals were found to fit simple sine curves. The equations of these sine curves were determined and combined to furnish an equation representing the relation between the water and air normals. The relations represented by the final equation are discussed, and the definite effects of the water on the air in this region are pointed out.

Introduction

One phase of the hydrographic investigations carried out by the Biological Board of Canada requires the recording of water temperatures throughout the year over a considerable portion of the Atlantic Coast waters. In this connection water and air temperatures at St. Andrews, N. B. have been recorded for several years past. The records from 1921 to 1929 inclusive have been analysed and form the subject matter of this paper1

Compilation of Data

From the recorded data, monthly normals for water and air have been determined and recorded in Table 1 and plotted in figure 1. Sine curves were found to fit these points quite closely. The equations of these curves are as follows:

Water $y_1 = 6.2 - 6.2 \sin. \frac{\pi(x+2)}{6}$

Air $y_2 = 6.0 - 12.4 \sin. \frac{\pi(x+3)}{6}$

where

y_1 = normal water temperature in degrees Centigrade

y_2 = normal air temperature in degrees Centigrade

x = time expressed in months.

The calculated values of y_1 and y_2 are also given in table 1.

The relation existing between y_1 and y_2 is given by the equation $y_1 = y_2 + .2 - 6.2 \sin \frac{\pi(x+2)}{6} + 12.4 \sin \frac{\pi(x+3)}{6}$
Using this equation and the observed values for the normal air temperatures, the values of y_1 have been calculated and recorded in table 2. The difference between these calculated water normals and the observed water normals is also noted in the table.

The use of these formula is limited by the following facts:

(a) The normals have been derived from the readings taken over a very short period. The taking of the air temperatures has suffered some interruptions and the normals are not as representative of the air as they should be.

(b) It must be remembered that the indicated relations are for the St. Andrews region. The hydrographic conditions in this region are very different from other parts of the coast.

(c) The errors in calculating the monthly normals as shown in the tables may be as large as 2.5°C.

(d) The monthly normals are representative of the temperatures at the middle of the month. In the case of the water temperatures it must not be presumed that there is anything like a regular gradation throughout the month. The daily water temperature is dependent upon many factors such as sunshine, air temperature, wind, tidal amplitude, and time of tide.

(e) It is possible to determine sine curves which will fit the observed values with greater accuracy. To do this it would be necessary to determine weekly normals. This would result in an increased amplitude and a slight change in the factor determining the phase.
(f) In practice we are dealing with water and air in contact. The water and air both receive direct radiation from the sun, and an interchange of heat between the air and the water is continually taking place. The temperature as well as the other physical conditions of the air are necessarily determined by world conditions, but are susceptible to considerable moderation by local conditions.

Analysis of Results

The temperature relations between the water and the air can be rewritten in a simplified form as follows:

$$y_3 = y_1 - y_2 = .2 - 3.1 \sin \frac{\pi x}{6} + 7.0 \cos \frac{\pi x}{6}$$

where y_3 is the difference between the normal water temperature and the normal air temperature. This equation is also plotted in figure 1, and the calculated values of y_3 recorded in table 3.

By means of a simple analysis of the equation for y_3, the following results are obtained:

The greatest numerical values of y_3 are found to be,

$y_3 = 7.7$ at $x = 5.2$ ---------June 21st

$y_3 = 7.9$ at $x = 11.2$ -------December 21st-22nd

Similarly,

$y_3 = 0$ at $x = 2.2$ -----------March 21st - 22nd
and
at $x = 8.2$ -----------September 21st

The average positive value of y_3 is 5.0

and the average negative value of y_3 is 4.7

Summary and Discussion of Results

1. (a) The normal temperature of the water at St. Andrews at any time can be represented by a formula of the form

$$y_1 = 6.2 - 6.2 \sin \frac{\pi (x+2)}{6},$$

where y_1 is the temperature in degrees Centigrade, and x is the time in months.

(b) The normal temperature of the air at St. Andrews at any time can be represented by a formula of the form

$$y_2 = 6.0 - 12.4 \sin \frac{\pi (x+3)}{6},$$

where y_2 is the temperature in degrees Centigrade, and x is the time in months.

(c) The relation between the water and air normal temperatures at St. Andrews can be represented by a formula of the form

$$y_3 = .2 - 3.1 \sin \frac{\pi x}{6} + 7.0 \cos \frac{\pi x}{6},$$

where $y_3 = y_1 - y_2$

2. (a) On July 15th the maximum temperature of the air is reached.

(b) On August 15th the water reaches its maximum temperature.

(c) On January 15th. the minimum temperature of the air is reached.

(d) On February 15th the water reaches its minimum temperature.

(e) On June 21st y_3 has its greatest negative value, i.e. the temperature gradient between the air and the water has reached its greatest positive value.

(f) On March 21st y_3 is equal to zero, i.e. the temperature gradient between the air and the water is zero.

(g) On September 21st y_3 is equal to zero, i.e. the temperature gradient between the air and the water is zero.

(h) On December 21st y_3 has its greatest positive value, i.e. the temperature gradient between the air and the water has reached its greatest negative value.

(i) The average positive value of y_3 is 5.0

(j) The average negative value of y_3 is 4.7

The annual movements of the sun with reference to some fixed point on the earth being truly periodic various periodic effects are produced. Atmospheric conditions remaining constant, a determination of the intensity of radiation falling on a chosen area would show an annual variation following a periodic law. In such a case a very shallow body of water would exhibit a similar periodic variation in temperature. If the depth of the water was considerable a pronounced lag in the water temperatures would be noted.

In the practical case atmospheric conditions are anything but constant, and the various bodies of water that concern us are usually subjected to agencies other than the heat from the sun which tend to determine the temperatures of the surface waters. To illustrate, various waters are frozen over throughout many months of the year with the result that the upper layers of the water remain practically constant throughout those months. Other waters are subjected to the influence of the waters of very pronounced currents which may supply either warm water or cold water containing much drift ice or icebergs. If an area in an open ocean is considered which is comparatively free from such influences it is found that the temperatures of the surface waters do follow a periodic law, particularly if the temperatures over a number of years are studied.

Similarly if the temperature of the air was determined solely by the heat received from the sun, the temperatures would follow a periodic law. Air movements, the results of world conditions are one of the many factors which enter into the determination of the air temperatures. Atmospheric conditions affecting the amount of the sun's heat which is able to reach the layers of air in contact with the surface of the earth are other factors which enter. The nature of the surface of the earth with which the air is in contact is still another factor which might be mentioned. Consequently air temperatures depart considerably from a periodic law. A periodic variation is usually approximated to in many localities.

The temperatures of the surface waters in the St. Andrews region are peculiar to the region. A large body of water is concerned with tidal effects which bring about an interchange of surface and bottom water on a large scale. This volume action is responsible for the storing of heat absorbed, and for the releasing of heat when a transference from water to air can take place. That this storing of heat does take place on a large scale is shown by the marked lag of the water temperatures behind those of the air.

The interchange of heat between the air and the water would be controlled by a number of factors. Definitely the temperature gradient would play a large part in determining the magnitude and the direction of the interchange. For this reason it is of interest to note the times of the year when the temperature gradient has its maximum and minimum values. The interesting coincidence between these dates and the positions of the sun with reference to the earth's equator is also worthy of note.

The average positive value of y_3 is approximately equal to the average negative value of y_3. Hence, in so far as the temperature gradient is concerned, the influence of the water on the air in this region must be approximately the same as the influence of the air on the water.

Conclusion

The hydrographic work of the Biological Board of Canada is concerned with the investigation of the physical conditions of the various waters of our coasts. In the investigation of the various regions the physical conditions of the surface waters usually presents valuable information as to the mechanism involved in determining the hydrographic conditions in the region. The physical conditions of the air over the region are also found to be of considerable importance.

In the St. Andrews region much valuable data has been collected over a period of years. In proceeding to analyse this data a treatment of the air and surface water temperatures is first attempted. The average condition over a period of years is thus presented. This will be followed by a treatment of the conditions to be found at the various depths, and a discussion of the mechanism that is responsible for the hydrographical conditions of the region.

TABLE I

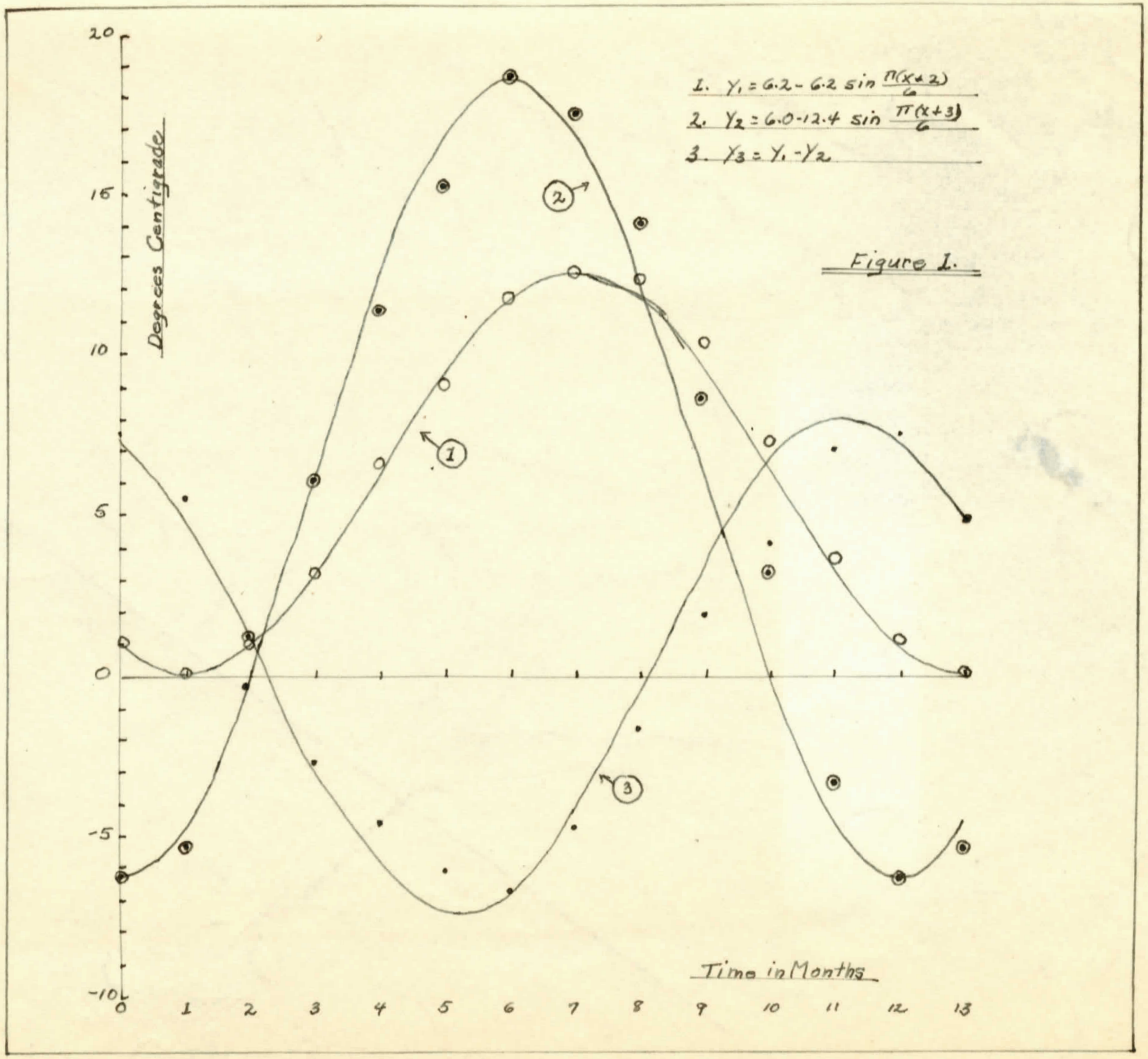
	Air Normals			Water Normals		
	Observed Values (a)	Calculated from equation (b)	a-b	Observed Values (c)	Calculated from equation (d)	c-d
Jan.	-6.4	-6.4	0.0	1.0	0.8	0.2
Feb.	-5.4	-4.7	-0.7	0.0	0.0	0.0
March	1.1	-.2	1.3	0.9	0.8	0.1
April	5.9	6.0	-0.1	3.1	3.1	0.0
May	11.2	12.2	-1.0	6.5	6.2	0.3
June	15.1	16.7	-1.6	8.9	9.3	-0.4
July	18.4	18.4	0.0	11.6	11.6	0.0
Aug.	17.3	16.7	0.6	12.4	12.4	0.0
Sept.	13.9	12.2	1.7	12.1	11.6	0.5
Oct.	8.5	6.0	2.5	10.2	9.3	0.9
Nov.	3.1	-.2	3.3	7.1	6.2	0.9
Dec.	-3.4	-4.7	1.3	3.5	3.1	0.4

TABLE 2

	Observed Values Air Normals	Observed Values Water Normals	Calculated water normals	Error
Jan.	-6.4	1.0	0.8	-0.2
Feb.	-5.4	0.0	-0.7	-0.3
Mar.	1.1	0.9	2.1	1.2
Apr.	5.9	3.1	3.0	-0.1
May	11.2	6.5	5.2	-1.3
June	15.1	8.9	7.7	-1.2
July	18.4	11.6	11.6	0.0
Aug.	17.3	12.4	13.0	0.6
Sept.	13.9	12.1	13.3	1.2
Oct.	8.5	10.2	11.8	1.6
Nov.	3.1	7.1	9.5	2.4
Dec.	-3.4	3.5	4.4	0.9

TABLE 3

	Observed	values		Calculated
	y_1	y_2	$y_3=y_1-y_2$	y_3
Jan.	1.0	-6.4	7.4	7.2
Feb.	0.0	-5.4	5.4	4.7
Mar.	0.9	1.1	-0.2	1.0
Apr.	3.1	5.9	-2.8	-2.9
May	6.5	11.2	-4.7	-6.0
June	8.9	15.1	-6.2	-7.4
July	11.6	18.4	-6.8	-6.8
Aug.	12.4	17.3	-4.9	-4.3
Sept.	12.1	13.9	-1.8	-0.6
Oct.	10.2	8.5	1.7	3.3
Nov.	7.1	3.1	4.0	6.6
Dec.	3.5	-3.4	6.9	7.8



1. $Y_1 = 6.2 - 6.2 \sin \frac{\pi(x+2)}{6}$
2. $Y_2 = 6.0 - 12.4 \sin \frac{\pi(x+3)}{6}$
3. $Y_3 = Y_1 - Y_2$
Degrees Centigrade
Time in Months
20
15
10
5
0
-5
-10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3

Figure 1.